WEST VIRGINIA COMMUNITY AWARENESS AND OPINION OF WATER AND HYDRAULIC FRACTURING

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ABSTRACT

The need for cleaner energy sources has driven a boom in oil and gas extraction via hydraulic fracturing. However, significant environmental issues that have been raised in response to this rapid expansion of fracking. Most of the scientific research has focused on potential water contamination (methane or toxic chemicals) or seismic activity related to drilling or wastewater injection, but there has been little research on the impacts of fracking on local communities that are directly affected by oil and gas activity. Communities are often without an avenue to voice their opinion or to discuss how they are affected by the rapid rise in fracking with scientists, politicians or industry. Opinion surveys collected from residents in West Virginia who live near hydraulic fracturing operations were analyzed and compared to groundwater drinking well water tests to determine how residents who live in areas impacted by oil and gas drilling feel about hydraulic fracturing and if certain informational inputs (online reports vs. well water data) impact residents' opinions.

Survey data was collected in Doddridge and Tyler counties of West Virginia from 27 residents whose water was either being tested for the first time or being retested by researchers at Duke University. The participants were asked about their knowledge and opinions of hydraulic fracturing and water quality issues in their community. Their answers were analyzed by qualitative and spatial analyses using STATA and ArcGIS. The survey data results were compared to selected chemical results from the participants' drinking well water samples.

The results from the project showed that, overall, the residents surveyed disliked fracking, those residents who received information from online reports were more likely to have negative opinions of fracking, residents who had received water testing services for their groundwater before taking the survey were more likely to consider their water quality in their opinion, and residents who had more information about their water supplies were more invested in water issues that could arise in the future due to fracking activities. Although the survey had limited respondents, it gives valuable insight into how scientific data may impact the opinions of water quality issues and hydraulic fracturing for residents in northwestern West Virginia.

TABLE OF CONTENTS

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INTRODUCTION

The United States is currently undergoing an energy revolution in the drive to become independent of foreign energy imports. The use of hydraulic fracturing has been one of the major technological advances that is contributing to the rapid rise in natural gas extraction. Hydraulic fracturing is a means of extracting fossil fuels from deep, impermeable rock formations by using high volume and high-pressure pumps to inject water, sand, and chemicals into the ground to cause small fractures that allow for increased access to oil and/or methane (Halliburton 2015). This method of fossil fuel extraction, along with the ability to drill directionally (i.e. horizontally), has led to a rapid increase in oil and gas activity in parts of the Appalachia region and West Virginia, which lie above the Marcellus Shale formation (Lieskovsky 2014).

Possible Environmental Impacts

One of the main concerns about fracking are the potential environmental and health impacts. Environmentalist mainly focus on issues of drinking water contamination, damage to natural resources, health problems from air and water pollution, use of scarce water resources, and greenhouses gas emissions (Dutzik et. al. 2012; Ridlington and Rumpler 2013). Those concerned state that fracking is intrusive, at high risk for well failures or accidental spills, and that the possible negative outcomes outweigh the benefits of increased natural gas extraction (Dutzik, et. al. 2012; Ridlington and Rumpler 2013). These issues have even led to the banning of fracking in the state of New York and moratoriums in numerous other states (Keep Tap Water Safe 2015). Other issues include the possibility of a “boom bust cycle” in which jobs are brought to the area by the oil and gas industry and then lost once the economic viability of the practice diminishes (Dutzik, et. al. 2012). Those in favor of fracking point out that it will help the United States become energy independent, that natural gas is a cleaner alternative to coal, and that fracking reduces carbon dioxide emissions (Energy from Shale 2015).

Previous scientific research has found that flowback fluids (fluid brought to the surface during or directly following drilling) and wastewater produced during fracking contain high levels of halogens (chloride, bromide, iodide), heavy metals (barium), naturally occurring radioactive materials (radium) and ammonium (Warner, et al. 2013; Harkness, et. al. 2015). In the Marcellus region, wastewater is mainly recycled (90%), injected into deep underground wells, injection or disposed of at centralized treatment facilities (Publicly Owned Treatment Works, POTW), or occasionally spread on roads for deicing purposes when other options are unavailable (Conti 2015; Vengosh, et al. 2014; Harkness, et. al. 2015; ALS 2015). All of these disposal methods have the potential to cause water contamination either by seepage into the environment or direct contamination through permitted or accidental release.

U.S. Groundwater Issues

In the United States, millions of residents have threatened water resources and limited opportunity for cheap, efficient testing of their drinking water. Complete drinking water assessments can be expensive if there is the possibility of a non-common contaminant in the water (FracFocus 2015). This is especially true for those living near energy extraction sites. West Virginia, in particular, requires no additional water testing regulations for fracking operations in terms of surface water, groundwater, or baseline testing (ALS 2015). Studies have suggested that high densities of unconventional drilling are associated with more accidental release events that can lead to contamination of drinking water resources (Warner, et. al. 2014). There is also the potential for well failures to lead to stray gas contamination of drinking water sources near drilling that could result in hazardous accumulation of methane in drinking water wells (Jackson, et al. 2013; Darrah, et al. 2014). Fracking also uses millions of gallons of water for each well, per frack (FracFocus 2015), which could put pressure on the local water systems if too much water is taken from streams or aquifers.

Survey Analysis Research

The purpose of this study was to determine how aware residents that live near hydraulic fracturing practices in West Virginia are of drinking water quality, what their opinions are on hydraulic fracturing, and if they believe hydraulic fracturing affects drinking water quality and availability. They were also asked if they believe that their family members' health was affected by hydraulic fracturing, and how their views have changed about their water quality and hydraulic fracturing before and after their groundwater was tested. Another goal of this project was to understand how local residents find information regarding fracking and the role that scientific research on water quality in these areas plays in helping to educate communities about fracking and water resources. This is especially important for scientists and decision makers who are trying to communicate with local communities about the risks or rewards of fracking. This information could also be useful for NGOs or advocacy groups that are trying to empower individuals or communities to be more involved in the regulation and protection of their drinking water resources.

The expected results from the analysis were that residents with poorer water quality would have a negative opinion on fracking and that their other survey responses would reflect similarly to this opinion. Residents' opinions on fracking were also believed to be dependent on whether their water had been tested multiple times or only once, depending on the significance of their water quality results and if chemical amounts were found to be higher than safe drinking water standards. Also, residents that live closer to fracking wells would have lower opinions of fracking, because of the more direct impact to their daily lives.

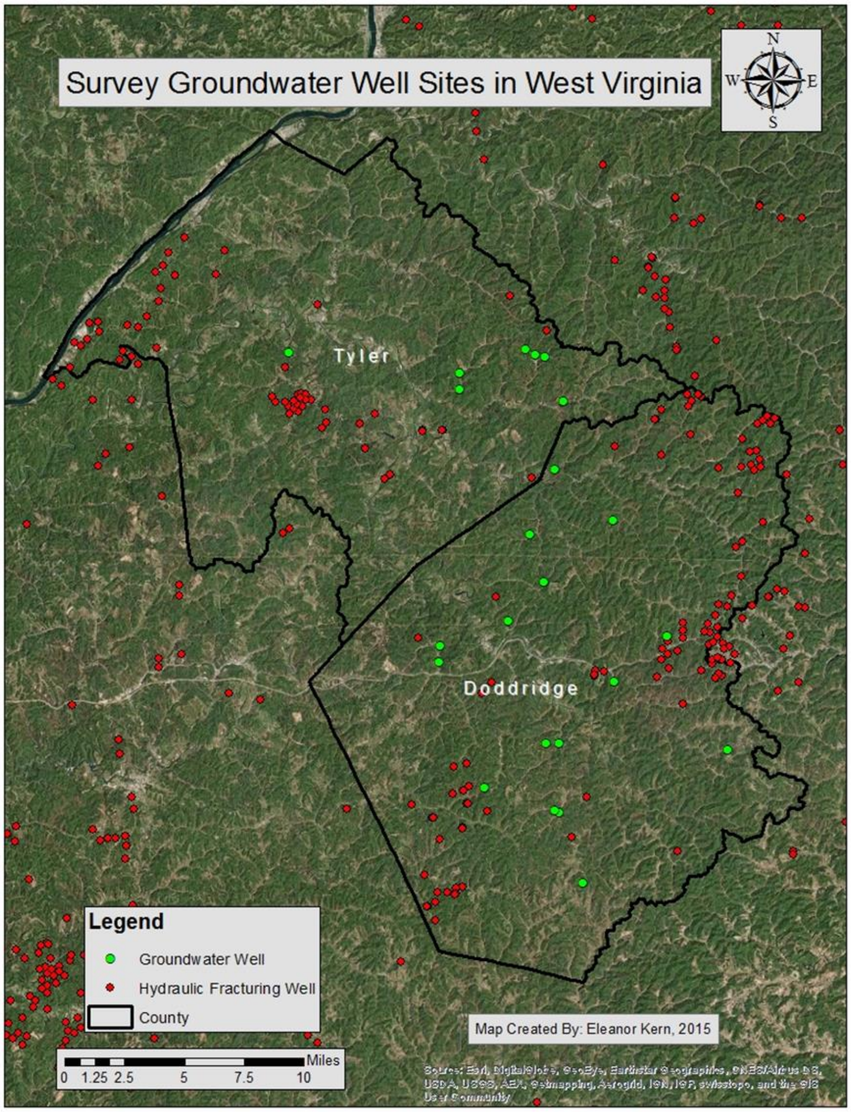

Figure 1: Location of Survey Sites and Hydraulic Fracturing wells with Coordinate Data.

METHODS

Survey Methods

Surveys were distributed to Doddridge and Tyler county residents whose drinking water was being tested as part of a groundwater study by researchers at Duke University. The survey asked residents about their knowledge of hydrology, hydraulic fracturing, and miscellaneous information about their academic history and living situation. The subject population included residents who currently live in West Virginia and are located near hydraulic fracturing activity or residents who once lived near hydraulic fracturing activity. The pool of possible participants included those who had received water testing once before (Retest participants) and residents whose water had never been tested before (New test participants) by Duke University. The locations of those included in the study can be viewed above in Figure 1 and the location of the study corresponding to the location of the Marcellus Shale basin can be viewed as Figure 2 in the Appendix.

Before the survey analysis began a Request for Protocol Approval was filed and approved by the Institutional Review Board (IRB). This procedure helped guarantee that the study would not negatively affect the participants mentally or physically, that the participants' identities were protected, and that the study was transparent for those involved. Analysis of the survey data accounted for different factors that affect whether an individual supports or disproves of hydraulic fracturing and the survey distributor tried to remain non-influential when asking questions concerning opinions of hydraulic fracturing (Davis and Fisk 2014). The survey was designed using the online program Qualtrics. The study was assigned under *Kern & Vengosh #C0405* with the IRB. An oral consent form was included with the survey for participants to sign before participating in the survey.

The subjects were recruited by a local resident from a pool of candidates selected for water testing by Dr. Avner Vengosh's group at Duke University. The participants had already agreed to participate in water testing through the Duke groundwater study and were recruited for the survey analysis while their water samples were being collected. The possible participants were contacted by phone, e-mail, mail, and in person to consent to having their water test results be a part of the analysis, and if they would like to be included in the survey. Participation in the study was completely voluntary. The survey answers were collected from summer to fall of 2014. The oral consent form was administered to the subjects who participated and a written form of the oral consent was given to the subjects to sign.

The answers from the surveys were analyzed by STATA using the Tab, Pwcorr, Sig, and Col queries to determine percent total and cumulative percent for each question, regression analyses, and compared to determine significant relationships between survey answers. The retest water results were ran first and then the new water test results were compared by statistical significance. The survey results were also compared to the water analysis results in Excel through graphical representation, the Correl function, and using the above-mentioned STATA queries. The answers from the survey and water analyses were compared to determine if the residents did their own research before and/or after receiving their water chemical analysis results, and how the water tests may have influenced resident opinions.

Water Analysis Methods

Water from the participants' drinking wells were analyzed at Duke University and mailed to residents. The results were compared to the Maximum Contaminant Levels (MCLs) for safe drinking water established by the US Environmental Protection Agency to inform the residents on the acceptability of their drinking water. Water samples were collected from unfiltered sources, either from an outside spigot or inside the home. If residents' wells were contaminated then they were informed, but were not given additional information about how their drinking water had become polluted. The water data was analyzed by using ion chromatography (for major anions), inductively coupled plasma-mass spectrometry (ICP-MS) (for trace metals), and directly coupled plasma – optical emission spectrometry (DCP) (for major cations) at Duke University. Methane concentration in drinking water were measured on a Picarro Analyzer. Only residents who had viewed their water quality results (Retest subjects) before the survey was administered were included in the water quality analysis.

Water chemistry parameters that were used in the statistical analysis included chemicals where multiple survey participants had amounts over the primary or secondary standard. Arsenic and manganese were used in the STATA and Excel analyses. These elements were in greater amounts than most of the other trace elements measured and residents were notified if their concentrations exceeded water quality standards. Arsenic and manganese were not chosen because of any correlation to fracking activities or possible contaminants from fracking. The chemicals were chosen for the opportunity to view how the survey subjects interpreted their water quality results.

Toolset Methods

The toolset was designed in ArcGIS to help the user input fracking well site data, home water well site data, and collected survey results to determine which households were near (<1km) fracking and other energy extraction sites, and if this affected their water quality or opinions on fracking. This was done by comparing tested drinking water data from the home and homeowner survey results to West Virginia's Energy Bill's water testing rules minimum distance from a drill pad to a home or drinking well, which is 650 feet from an occupied dwelling (Carducci 2012). The ArcGIS tools used in the toolset included Select, Buffer, and Euclidean Distance. The tool also helped compare between year and month of fracking well completion and when water was collected from homes.

Currently the toolset is only for educational use in Dr. Avner Vengosh's laboratory. Only files that fit within the specific parameters detailed in the model can be used to run analyses in the toolset. These parameters can be changed within the model and are detailed in the Appendix. The files used for the toolset were collected and provided by Dr. Avner Vengosh's laboratory.

Models in Toolset

- Analysis of Fracking Well Data
  - This model used the energy extraction well point data to create a shapefile and buffer from user selected well completion year, well type, and buffer distance.
- Analysis of Home Water Well Data
  - The model created a shapefile and buffer of sample sites from a user selected collection year. It used the provided home water well data.
- Analysis of Homeowner Survey Data
  - The final model in the toolbox created shapefiles based on a user specified question and an answer to that specific question.

RESULTS

Survey Results

The STATA statistical analyses showed strong correlations and significant relationships between the following questions of the survey shown in Tables 1 and 2 below. The retest survey data was run first and then the new test survey data was compared to the retest results. Relationships from the new test analysis that had much less statistical significance than the retest results were highlighted in red and can be viewed in Table 1. Table 2 shows the questions corresponding with question codes used in STATA. The relevant resulting relationships were:

- Homeowners were more likely to know well depth, compared to renters, and have their drinking water tested recently.
- Residents who did research online were more aware of possible water contamination issues from fracking.
- Residents who knew the depth of their well were more likely to state that groundwater testing is important for human and environmental health and that water availability should be a primary concern for the future.
- Individuals with a positive opinion on fracking were more likely to agree that there would still be enough water for their family if a major chemical spill occurred.
- Pro-fracking individuals agreed that groundwater wells are not affected by fracking.
- Women were more likely to know more about fracking and to have done previous research.
- Residents with higher levels of education knew more about water quality.
- Individuals with deeper wells were more likely to say that their water was not clean.
- Residents with a negative opinion on fracking were more likely to have done research online before taking the survey.
- Residents who believed that hydraulic fracturing had affected their family's health were more detailed in their written responses.

Figures 3a, 3b, and 4 in the Appendix show a graphical representation and comparison of the questions with higher R-values for retest and new test water data. More comparative relationships between the different questions were not shown graphically because of the limited and variable nature of the survey responses, which will be described in more detail in the discussion section of this analysis. The entire survey can be viewed in the Appendix.

Relationships between the water quality data and certain survey questions that were found through STATA analysis are shown in the next section.

Table 1: Survey Question Relationships with Significance

		Re-Test Results		New Test Results	
Question 1	**Question 2**	**R (Correlation)**	**P < 0.05 (Significance)**	**R (Correlation)**	**P < 0.05 (Significance)**
q10	q5	0.7434	0.0006	0.6770	0.0110
q13_4	q12	0.7751	0.0003	0.5367	0.0586
q23_2	q29	-0.5708	0.0167	-0.0479	0.8764
q23_3	q10	0.5530	0.0213	0.0833	0.7867
q23_4	q10	0.5952	0.0117	-0.0833	0.7867
q23_4	q23_3	0.8530	0	0.9500	0
q23_5	q43_1	-0.5011	0.0405	-0.5842	0.0360
q23_5	q23_2	0.8654	0	0.3805	0.1997
q24	q12	0.5439	0.024	0.6149	0.0253
q27	q34	0.5632	0.0186	0.1359	0.6581
q31	q11	0.4968	0.0425	0.0815	0.7912
q33_1	q10	0.5401	0.0252	-0.1231	0.6887
q43_1	q23_2	-0.4837	0.0492	-0.6687	0.0124
q43_1	q12	-0.7816	0.0002	-0.2201	0.4699
q43_1	q13_4	-0.7558	0.0004	-0.4273	0.1453
q44	q13_5	-0.4792	0.0516	-0.2378	0.4341

Table 2: Assigned Codes Used in STATA for Significant Survey Questions

Question Code	Question
q5	Do you own or rent the home you live in?
q10	Do you know how deep your drinking water well is?
q11	Around what depth is your drinking water well in feet?
q12	Before taking this survey, were you aware of the possible pollutants from hydraulic fracturing to groundwater and surface water?
q13_4	Where would you go for information about hydraulic fracturing in the region?
	Answer: Online reports
q13_5	Where would you go for information about hydraulic fracturing in the region?
	Answer: Other please specify
q23_2	Groundwater wells are not affected by hydraulic fracturing.
q23_3	Groundwater testing is important for environmental and human health in the region.
q23_4	Water availability should be a primary concern in the future.
q23_5	If a major chemical spill occurs in the next few years, there will still be enough water for my household.
q24	What is your gender?
q27	What is the highest level of education you have completed?
q29	I there anything else you would like to tell us about water resources in your region?
q31	Would you say that the water quality of your drinking water is particularly clean?
q33_1	What reason do you believe that your water is dirty?
	Answer: I have tested my well water recently.
q34	Is groundwater always pure because soil filters out the impurities?
q43_1	What is your opinion on hydraulic fracturing occurring in your region from 10 (positive opinion) to 0 (negative opinion)?
q44	Do you believe that hydraulic fracturing processes have affected your family's health?

Water Analysis Results

Significant correlations found between the survey data and water quality data were:

- Residents with higher levels of arsenic (As) and manganese (Mn) in their drinking water were more likely to describe their water as not clean.
- There were relatively high amounts of arsenic in water samples from pro-fracking households, but amounts were not above water quality standards. This relationship will be discussed further in the discussion.

Table 3: Survey Question and Water Chemistry Relationships with Significance

Question	Chemical	R (Correlation)	P (Significance)
q31	As	0.5922	0.0157
	Mn	0.4905	0.0537
q43_1	As	0.7123	0.0020

Figure 5 shows the graphical representation of the relationship between q31 and manganese concentrations.

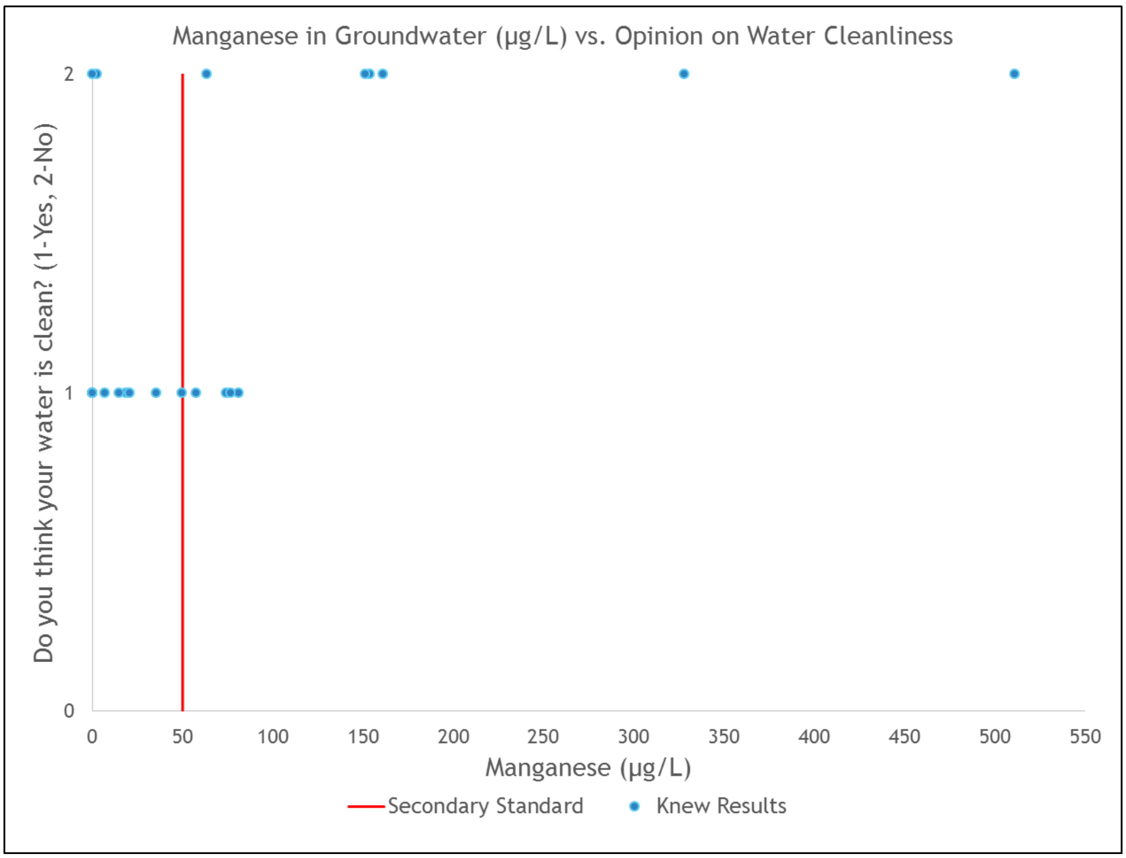

Figure 5: Manganese Concentrations (µg/L) Compared to Water Quality Opinion

A similar figure showing a graphical representation of the survey and water quality correlation for arsenic can be viewed in Appendix Figure 6.

GIS Results

The results from the geospatial toolbox focused on possible spatial relationships between the location of the residents' drinking water wells to fracking well locations and the geochemical data. Representations of outputs that were made from the toolset can be viewed in the Appendix as Figures 7 through 11. Spatial relationships between the survey and water quality data were difficult to quantify, but qualitative results were discussed. Geospatial results show that residents who stated that their water was unclean were more likely to have higher levels of manganese in their water (Figure 7). The concentrations shown in figures 8 and 9 were colored coded based on the water quality drinking standards for arsenic and manganese. Concentrations that were red were not within safe drinking standards, while concentrations represented in green were within safe standards. It was also found that those living closer to denser fracking operations were more likely to have a negative opinion on fracking, compared to those who did not live near fracking areas (Figure 10). The spatial interactions found in Figures 10 and 11 used the Near function in ArcGIS to compare resident drinking water well locations to fracking sites. Figure 12 represents those distances graphically.

DISCUSSION

Survey Discussion

The results of the survey analysis found an overall negative opinion of fracking in residents in the study area. Reasons for this outcome include: residents who were surveyed already had an interest in water quality testing, the location of the home to fracking operations causing a change in the home environment, and source of the residents' information on fracking. Figure 4 in the Appendix especially shows the divide in opinion based on where residents received their information on fracking. Residents who were more likely to receive their information from online report sites or from environmental awareness groups were more likely to have a negative opinion on fracking compared to those who received their information from energy websites or the newspaper.

Other reasons for the views that were represented in the data could be that residents search for information that will support an already formed opinion of what fracking is and what it does to the environment and water. Research that supports this type of behavior exists for views about other environmental issues such as climate change (Kahan, et. al. 2011). The majority of correspondents were women, comprising around 70% of those who took the survey. The women surveyed had gone through more years of schooling than the men in the survey, they were more likely to have done research on fracking compared to the men, and in households comprised of a man and a woman, and the woman was much more likely to take the survey compared to the man.

Since the 1980s women have been moving towards a more liberal viewpoint, while men are becoming more conservative (Zelezny and Bailey 2006). Davis and Fisk (2014) found a correlation between women and opposition of fracking in their analysis of public opinion on fracking. Women were found to support more regulation on drilling and chemical disclosure laws (Davis and Fisk 2014). Overall, the results of this project and other studies have found consistent evidence for women's support of environmental issues and opposition to fracking. The media source used by the residents also may have influenced their opinion, as women were twice more likely to use online environmental reports to gain information on fracking than men.

Media messages favoring different sides of a controversial issue can produce significant opinion changes (Davis and Fisk 2014). This can be seen in the survey results from the study as well. Those who obtained their information primarily from online sources were more likely to have a negative view compared to those who received information from newspapers, television, or other media. A person's perception of risk is influenced by the ability to successfully quantify that risk, technologies of visualization, quantification, and concrete results that justify action (Cartwright 2013). Fracking, compared to conventional oil and gas extraction technologies, is often viewed as very risky because there is a heightened awareness of possible dangers due to media sensationalism, incomplete scientific data to support or reject use, and the vague legalities of fracking technologies (Cartwright 2013).

Statistical Discussion

The statistical data for the survey analysis found that there was a stronger correlation between the resident retest survey responses than for the new test residents' survey responses when comparing similar survey responses between multiple questions. This relationship can be clearly seen in Table 1. These results seemed conclusive until they were graphed and compared. By looking at the graphs it could be seen that the results were very similar except for one or two responses. Because of the limited amount of residents surveyed, the statistical significant and correlation calculated in STATA and Excel was not definitive and could easily be changed by only one survey response.

This finding was also problematic for the statistical comparison between the water quality results and the survey results. There was a definitive correlation found in STATA between the statistical and graphical results of the manganese concentrations and whether or not those surveyed believed that their drinking water was clean, but when comparing the statistical correlation of arsenic with opinions on fracking graphically, the correlation was found to not exist. Statistically, arsenic concentrations correlated with a positive opinion of fracking, but Figure 6 in the Appendix shows that the higher values were still within safe drinking water range. There was only one water sample above the water quality standard for arsenic and that one resident had a negative opinion of fracking. However, water wells with arsenic values just below the standard were associated with homeowners with positive opinions of fracking, which biased the correlation. These higher concentrations would not significantly change the homeowner's opinion, because they are within the range for safe drinking water quality.

Spatial Discussion

The spatial portion of the results showed a definitive relationship between the residents' opinion on fracking and the residents' distance from the nearest fracking well. The graph in Figure 12 shows that all the residents living within a mile of a fracking operation had a negative opinion of the practice. Residents that lived a farther distance from fracking were more likely to either be neutral or have a positive outlook on fracking. The reasons for this result could be that residents with more direct exposure to fracking activity such as automobile traffic, neighbors using water "buffalos" and other drinking water supplies provided by energy companies, more noise and light pollution from the heavy machinery and fracking process that is audible from their homes, and more interaction with the industry workers.

From Figures 8 and 9 it can be seen that there was no relationship found between locations of high concentrations of arsenic and manganese. The higher manganese concentration locations seemed to divide Doddridge County in the middle, but this finding could not be correlated with any data collected in this assessment. The high arsenic concentration locations were completely random, but drinking water wells that had arsenic concentrations above drinking water standards also had concentrations of manganese above the safe drinking water standard. This relationship is most likely because of the chemistry that influences arsenic and manganese concentration in groundwater. Low oxygen groundwaters are more likely to have high concentrations of both manganese and arsenic, while high oxygen groundwaters tend to have low concentrations.

CONCLUSIONS

Based on the analysis it can be concluded that residents who owned their home and tested their drinking water regularly were more likely to be aware of water quality issues and have a stronger opinion that water issues are important problems to worry about now and into the future. Most of the information that residents found about fracking was from the internet and those with a negative viewpoint were more vocal and more likely to believe that their water was polluted or could be polluted. Residents with positive views on fracking did not worry about water scarcity or water pollution problems in the future.

To combat the social issues raised in this paper, it is recommend that more education programs be provided for residents on hydrology and water quality issues pertaining to groundwater contamination, and that scientific communications between different interest groups and participants in the argument for and against fracking be established to try and work towards a better system of understanding and learning. This will lead to better water safeguards and infrastructures, less political disputes, and may even lead to a better way to develop energy that does not disrupt the lives of those who live near it.

Issues with the project that should be addressed in future similar studies include, helping residents differentiate between a survey and a quiz, having a longer amount of time to develop the survey and distribute surveys, finding easier ways to communicate with residents in the Appalachian region, and making sure that those surveyed are not already heavily biased and that survey collection is random. That was a major issue with this study, as most of the participants already had strong views on hydraulic fracturing and the sample size was small. Even with limited data, this research helped understand how residents collect their information on issues regarding hydraulic fracturing and determined that many residents in this specific region of West Virginia are not supportive of fracking.

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APPENDIX

TOOLSET

Analysis of Fracking Well Data

This part of the toolset can be used to choose the date the well was completed and what type of fossil fuel was being extracted from the well to create a shapefile of the specific sites that fit within those parameters. By inputting a specific distance in meters a buffer distance around the sites chosen in the created shapefile will be formed. Steps on how the data was formatted and how to use the model are below in steps 1A-1B.

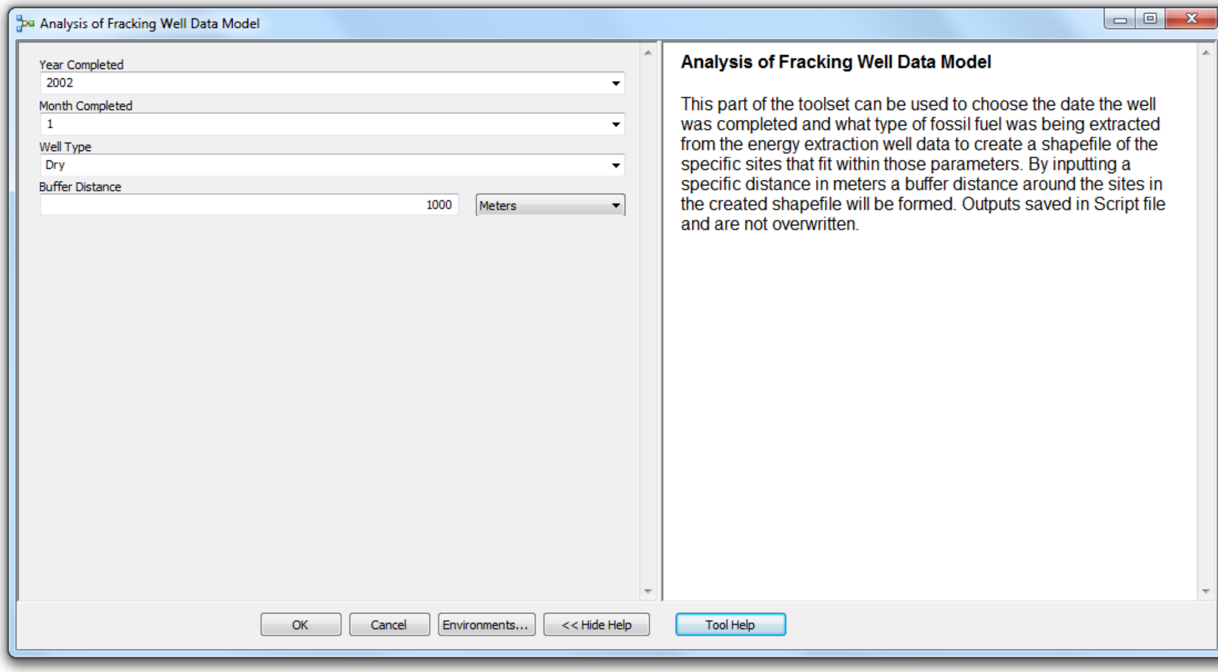
Step 1A – Data Format

The parameter used from the energy extraction well data to represent the year of completion was the CompYEAR field. To ease the process the CompYEAR data was changed from date to years by using Access. The WellType field was used for the fossil fuel parameter in the model. The specific years and well types were inputted into the model, with Row Count tools in place so if certain well types were not completed for certain years then the model won't run. When running the tool make sure that the coordinate system of your layers is the projected coordinate system NAD 1983 UTM Zone 17N, or the output will be warped. When inputting your new shapefiles, if a Geographic Coordinate System Warning occurs, just hit close.

Step 1B – Fracking Well Model Analysis

1. Choose the completion year from the 'Year Completed' value to choose well sites only completed in the given year. The years available are 2002 and 2004-2013.
2. Choose a well type from the 'Well Type' value to choose well sites of only the given type. The year value that was already chosen will still be in effect, so the well type will only be from the given year. The well types include, Dry, Dry w/ Oil Show, Gas, Gas w/ Oil Show, not available, and Oil and Gas.
3. Input a buffer distance in meters or another unit in the 'Buffer Distance' value. This distance will be for the data that fits within the 'Year Completed' and 'Well Type' selections.
4. If no data fits into your given selections, then the tool will return an error.
5. The model ouputs will be saved in your Scratch folder and multiple runs of the tool will not overwrite previously computed model outputs. The files' names will be descriptive of what information they contain.

*Note: A version of these instructions is also given in the tool.



Analysis of Home Water Well Data

For this part of the toolset, the homeowner well data can be used to show how close the homes are located relative to the fracking well sites. The home well data is used to create a shapefile and buffer that will be the mask for a premade Euclidean distance output showing estimated 1 mile and 2 mile areas around the fracking sites. To run the tool the user inputs the sample year and the desired buffer distance around the home sites. Steps on how the data was formatted and how to use the model are below in steps 2A-2B.

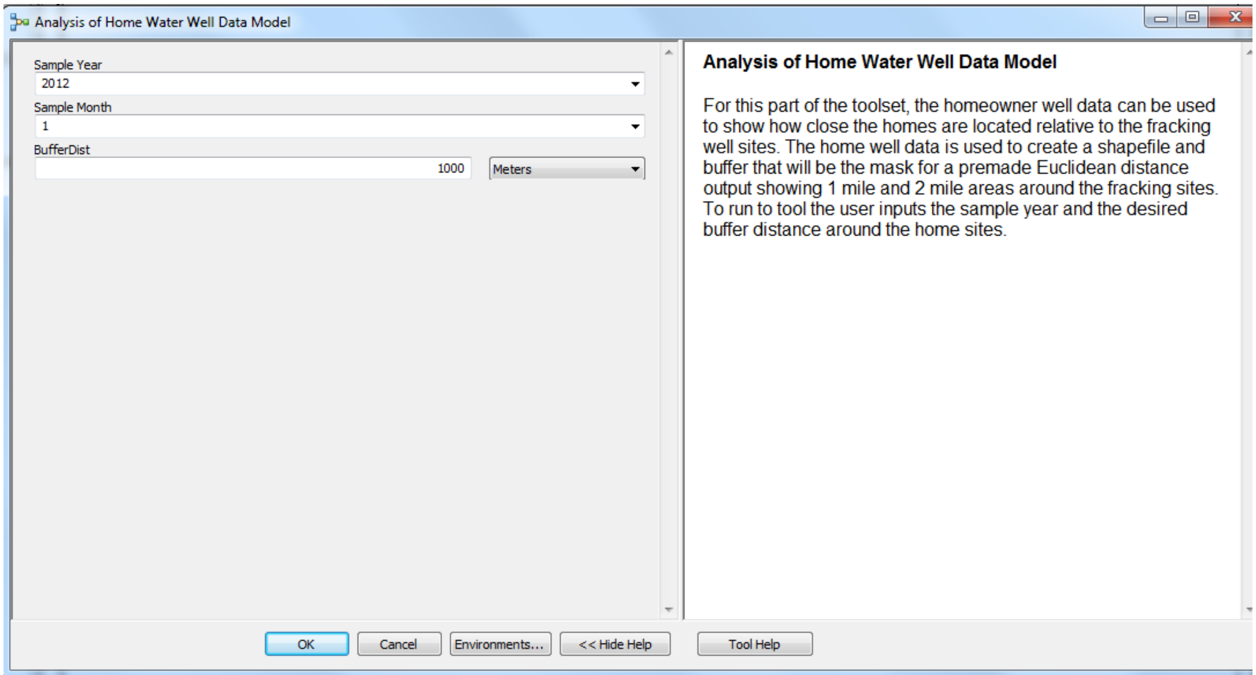
Step 2A – Data Format

The parameter used from the home drinking water well data to represent the year of it was samples was the SampleYEAR field. The specific years were inputted into the model, with Row Count tools in place so if wells were not sampled for certain years then the model won't run. The Euclidean distance raster was created outside the model and saved in the data folder to keep it from being accidentally deleted. The symbology of both the Euclidean distance and the mask of the Euclidean distance are saved, but the correct symbology can only be viewed by choosing to Add to Display by right clicking the Euclidean Distance and Extract by Mask tools in the edited version of the model. A Make Feature Layer tool needed to be added to the Buffer tool to keep it from malfunctioning. The reason behind this is not known, but the toolset works. When running the tool make sure that the coordinate system of your layers is the projected coordinate system NAD 1983 UTM Zone 17N, or the output will be warped. When inputting your new shapefiles, if a Geographic Coordinate System Warning occurs, just hit close.

Step 2B – Home Drinking Well Model Analysis

1. Choose the sample year from the 'Sample Year' value to choose well sites only sampled in the given year. The years include, 2012, 2013, and 2014.
2. Input a buffer distance in meters or another unit in the 'BufferDist' value. This distance will be for the data that fits within the 'Sample Year' selection.
3. If no data fits into your given selections, then the tool will return an error.
4. The model ouputs will be saved in your Scratch folder and multiple runs of the tool will not overwrite previously computed model outputs. The files' names will be descriptive of what information they contain.
5. To view the correct Euclidean distance and mask of Euclidean distance outputs, open the model to the edit view by right clicking the tool. When the edit view is open, right click the Entire Euclidean Distance output and choose Add to Display. Do the same for the Mask Euclidean Distance Output.

*Note: A version of these instructions is also given in the tool.



Analysis of Homeowner Survey Data

For this part of the toolset, the homeowner survey data can be used to show how certain survey answers might me spatially relevant. The survey data is used to create a shapefile of those chosen answer from a certain question. To run the tool the user inputs the question number and the desired answer from that question. Steps on how the data was formatted and how to use the model are below in steps 3A-3B.

*Note: This model in the toolbox was not asked for by the client and is only for my own Masters Project, so it is a simplified version of what the resulting model will become.

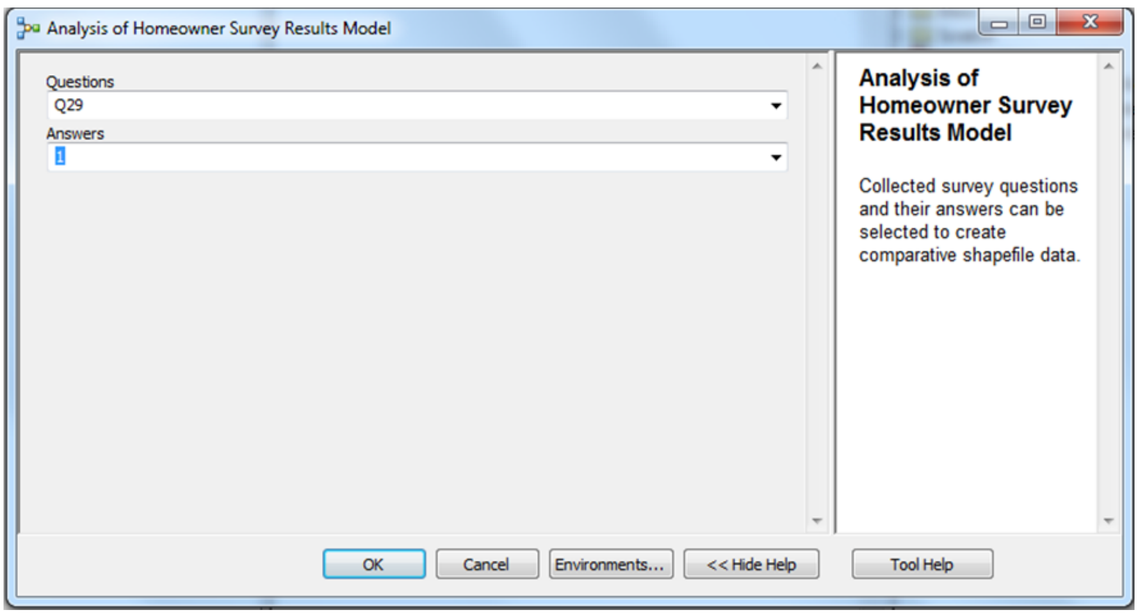
Step 3A – Data Format

The parameter used from the survey data to represent the questions were the Q fields with numbers following the Q. The answers from these questions were used for the answers field. The specific questions of interest and possible answers to each question were inputted into the model, with Row Count tools in place so if certain answers are not compatible for certain questions then the model won't run. When running the tool make sure that the coordinate system of your layers is the projected coordinate system NAD 1983 UTM Zone 17N, or the output will be warped. When inputting your new shapefiles, if a Geographic Coordinate System Warning occurs, just hit close.

Step 3B – Homeowner Survey Results Model Analysis

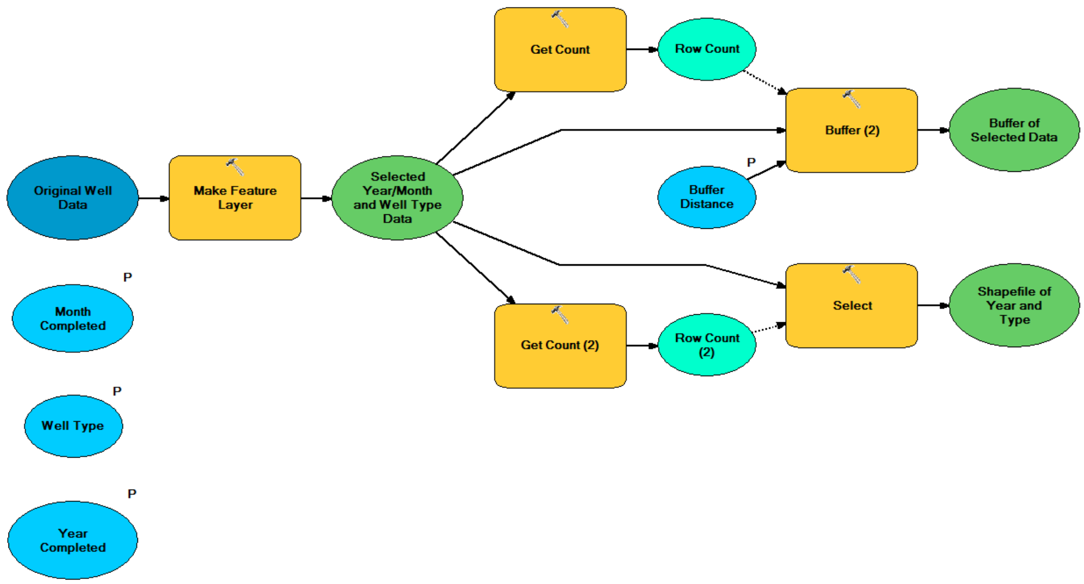
1. Choose the question of interest from the ‘Questions’ value to choose well sites only sampled in the given year.
2. Choose the answer of interest from the already chosen question from the ‘Answers’ value to create a shapefile of those answers. Possible choices range from 0 to 10.
3. If no data fits into your given selections, then the tool will return an error.
4. The model outputs will be saved in your Scratch folder and multiple runs of the tool will not overwrite previously computed model outputs. The files’ names will be descriptive of what information they contain.

*Note: A version of these instructions is also given in the tool.

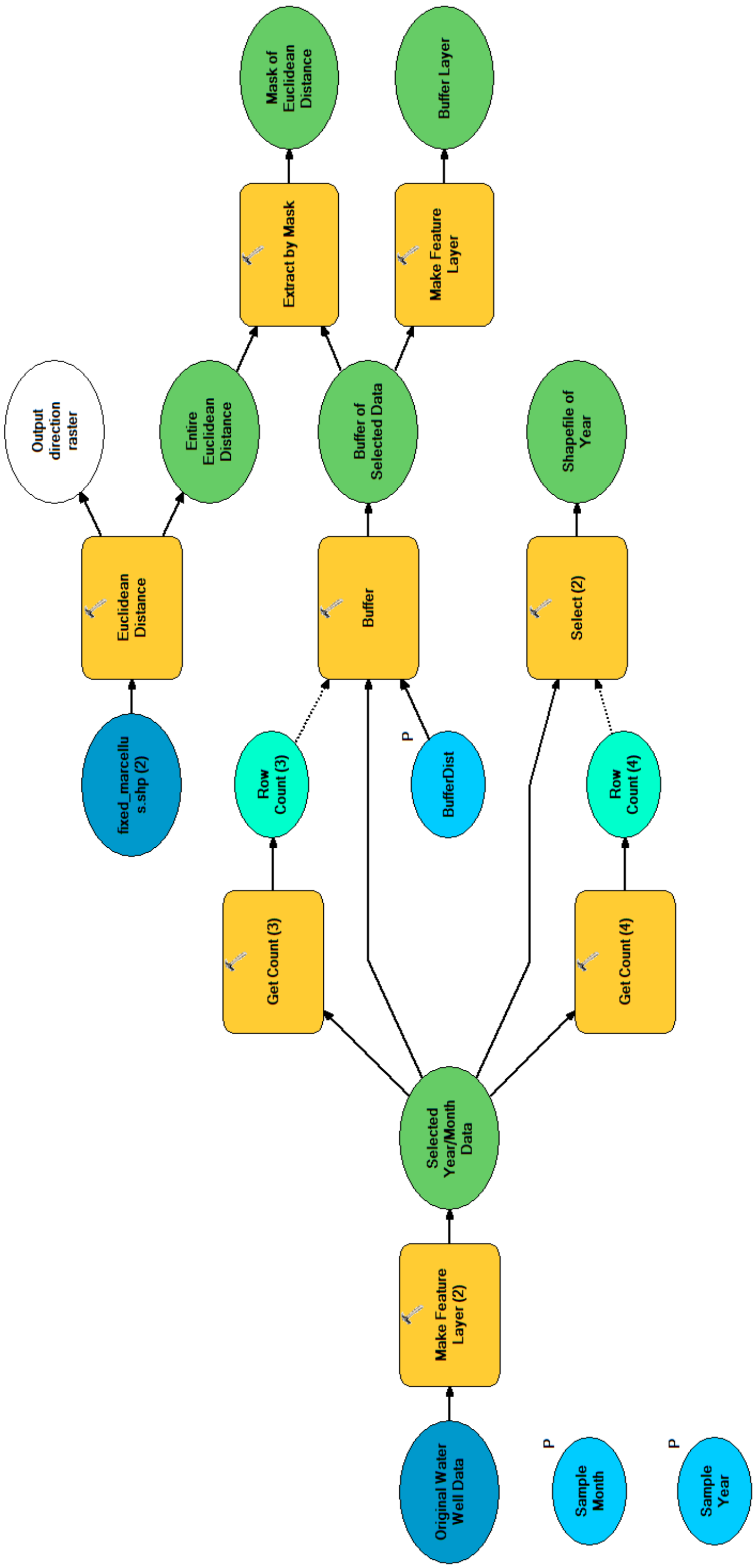


Geo-Processing Models

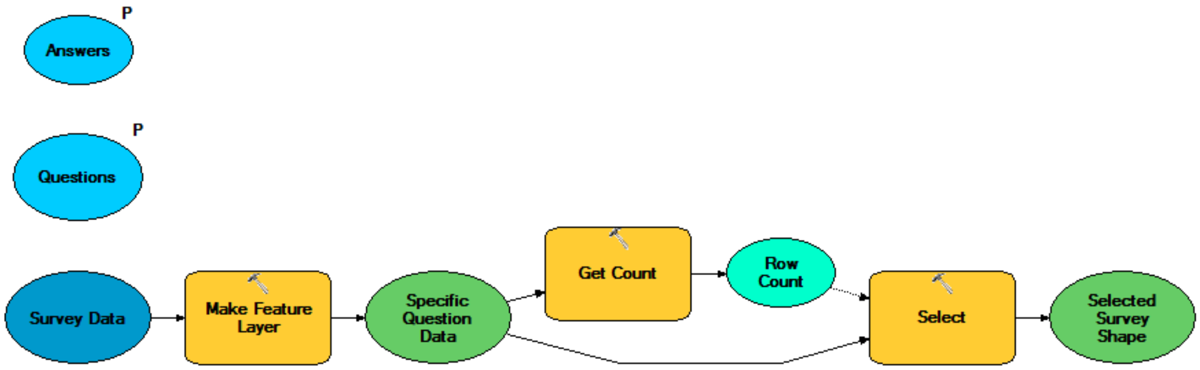
Step 1B – Fracking Well Model Analysis



Step 2B – Home Drinking Well Model Analysis



Step 3B – Survey Comparison Model Analysis



SURVEY

Oral and Written Consent Form

“This research is being conducted by myself, Eleanor Kern. I am a student at Duke University in Durham, North Carolina pursuing my Master’s degree in Environmental Management at the Nicholas School of the Environment. I am working under the supervision of Professor Avner Vengosh and this research is for my Master’s Project for graduation from the Nicholas School of the Environment. I will read you the oral consent for this survey and then have you sign the written version of this consent for documentation.

The purpose of this study is to understand how individuals view their drinking water quality and hydraulic fracturing practices. Participation in this study will require you to fill out a short initial survey which asks about the source of your drinking water, your knowledge of what might be in your drinking water, and some general information about you. We will ask you to allow your water to be tested, and then complete a second final survey after your well water tests results are in evaluating how your opinions and knowledge may or may not have changed in the process. The results of your well water test will be sent to you in the mail within the next few months. Benefits from this research include knowing the chemical makeup of your drinking water and any additional knowledge gained from the surveys. We will not record your name on the surveys’ information to make sure that your responses are confidential. I will ask for your mailing address in order to send your well water test results but this information will be stored separate your survey answers and will be deleted from our study records as soon as we have mailed your well water test results to you. You may choose to withdrawal at any point during the study and may choose to not answer any of the questions in the surveys. Participation in this study is completely voluntary. The surveys will take approximately 15 to 20 minutes each to complete.

All data collected in this study will be confidential. Random numbers will be used to organize the survey answers so that only I know the actual answers given and the data will be stored on a flash drive in a locked lab office. Your mailing address will be linked to your survey answers, but only through a random numeric that I will assign you. The locked office will be at Duke University in Durham, North Carolina and will only be accessible by our research team. The survey and water data will only be used for research purposes and will only be accessed by us. The files with the information collected for this survey will be destroyed after April 2015 when the results are presented at the Master’s Symposium in Durham, North Carolina. They will not be shown to any other organization or government group. If you wish to discontinue with the study your information will be destroyed.

Any questions about the human rights of subjects can be directed to the Human Subjects Committee at 919-684-3030 or ORS-Info@duke.edu.

If you have any questions or concerns please feel free to contact my advisor, Dr. Avner Vengosh at 919-681-8050 or at Vengosh@duke.edu, or myself at 937-830-5099 or at efk11@duke.edu.

If you have any questions or would like for me to repeat anything that I have just said please let me know now."

______________________________ __________________

Name of person taking consent Date

Survey

Dear residents of West Virginia:

I am currently a student at the Nicholas School of Environment at Duke University and I am conducting a survey of households that receive their drinking water from groundwater wells and live in regions in proximity to hydraulic fracturing practices. This survey was designed to collect data on the public awareness of water quality and hydraulic fracturing in West Virginia. The information you provide will be useful for future water related research and education.

This survey will take about 10 to 15 minutes to complete. There are no correct or incorrect answers to any question, and all responses will be treated confidentially. Taking this survey is voluntary, and you may skip any question at any time.

Thank you very much for your participation.

What are your initials?

Is this the first time that you have had your drinking water tested by Duke University?

- Yes, I have only had my drinking water tested by Duke University once.
- No, I have had my drinking water tested by Duke University more than once.

What is your zip code?

How long have you lived in your region?

Please round to the nearest year.

- 0 to 2 years
- 3 to 5 years

- 6 to 10 years
- More than 10 years
- Other

What type of home do you live in?

- Single family home
- Townhouse
- Mobile home
- Duplex
- Apartment
- Condo
- Dormitory
- Other (please specify):

Do you own or rent the home you live in?

- Own
- Rent
- Other

Do you know how deep your drinking water well is?

- Yes
- No

Around what depth is your drinking water well in feet?

- 10-30
- 31-40
- 41-50
- 51-60
- 61-70
- 71-100
- I don't know
- Other

Groundwater is always pure because soil filters out the impurities.

- True
- False

If the water tastes good, it is safe to drink.

- True
- False

Would you say that the water quality of your drinking water is particularly clean?

- Yes
- No

What is the reasoning for believing your water is clean? Select any that apply.

- I have tested my well water recently
- The water is clear

- The water does not have a bad taste
- The nearby streams are in good condition
- I am currently not sick from the water
- Other

What reason do you believe that your water is dirty?

- I have tested my well water recently
- The water is discolored
- The water has a bad taste or odor
- The nearby streams are in bad condition
- I am currently sick from the water
- Other

Before taking this survey, did you know that there are ways to test your own well water and drinking water for possible contaminants?

- Yes
- No

Have you had your drinking water tested in the past?

- Yes
- No

Which of the following testing have you heard of?

- Testing by State Health Laboratory
- Conductivity meters
- Well water testing kits
- Professional water testing labs

What are possible contaminants that are indicators of water quality? Select all that apply.

- Total coliforms
- pH
- Fecal coliforms
- VOCs
- Nitrate
- Salts
- Metals

Before taking this survey, were you aware of the possible pollutants from hydraulic fracturing to groundwater and surface water?

- No, I was not aware
- Yes, but I've never researched the facts myself
- Yes, and I've read articles on hydraulic fracturing

Where would you go for information about hydraulic fracturing in the region? Check all that apply.

- Newspapers

- TV news
- West Virginia energy website
- Online reports
- Other please specify:

What is your opinion on hydraulic fracturing occurring in your region from 10 (positive opinion) to 0 (negative opinion)?

Do you believe that hydraulic fracturing processes have affected your family's health?

- Yes
- No
- I don't know

Please indicate your agreement or disagreement with the following statements.

Completely Agree Agree NeutralDisagree Completely Disagree Don't Know

There is currently enough water to supply the population of West Virginia.

Ground water wells are not affected by hydraulic fracturing.

Ground water testing is important for environmental and human health in the region.

Water availability should be a primary concern in the future.

If a major chemical spill occurs in the next few years, there will still be enough water for my household.

What is your gender?

- Male
- Female
- Prefer not to answer

What is your age?

- 21 or under
- 22-34
- 35-44
- 45-54
- 55-64
- Over 65
- Prefer not to answer

What is your race?

- White/Caucasian
- African American
- Hispanic
- Asian
- Native American
- Pacific Islander

- Other
- Prefer not to answer

What is the highest level of education you have compelted?

- Less than High School
- High School/GED
- Some college
- 2-year college degree
- 4-year college degree
- Master’s degree
- Doctoral degree (PhD)
- Professional Degree (JD,MD)
- Prefer not to answer

What is your annual household income level?

- Below $20,000
- $20,000-$29,999
- $30,000-$39,999
- $40,000-$49,999
- $50,000-$59,999
- $60,000-$69,999
- $70,000-$79,999
- $80,000-$89,999
- $90,000 or more
- Prefer not to answer

Is there anything else you would like to tell us about water resources in your region?

Where did you get this survey?

- Email list
- Paper slip with link
- Forwarded from a friend
- Other

FIGURES

Figure 2: Location of Study Area in West Virginia and Marcellus Shale Basin (nyc.gov)

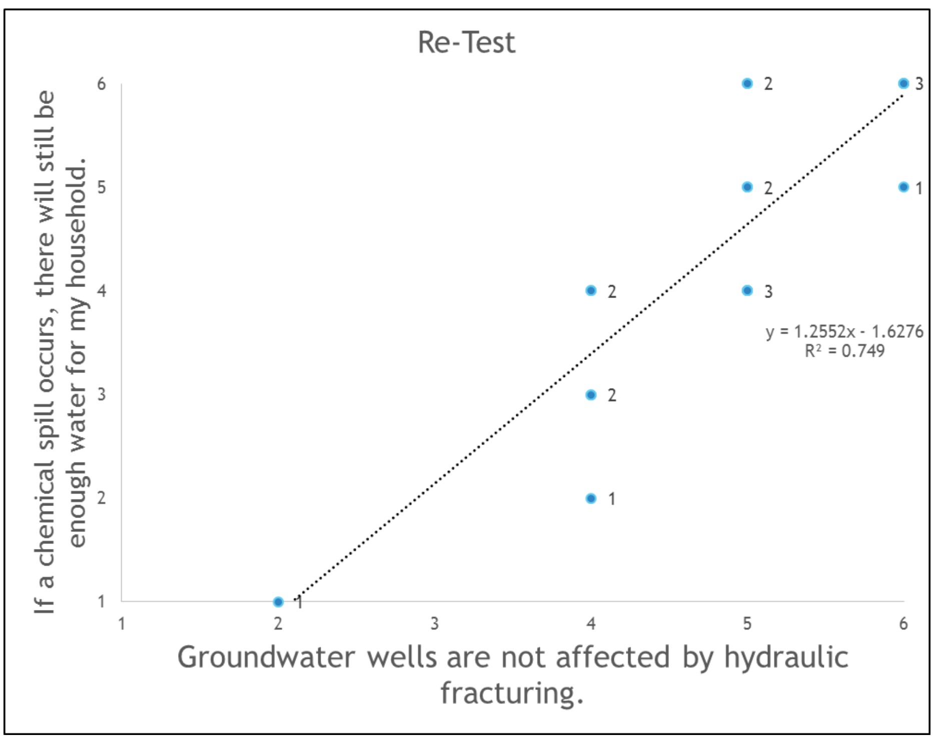


Figure 3a: Comparison Between Questions q23_2 and q23_5 for Retests (The numbers next to the specific opinions represent the number of residents with that specific opinion.)

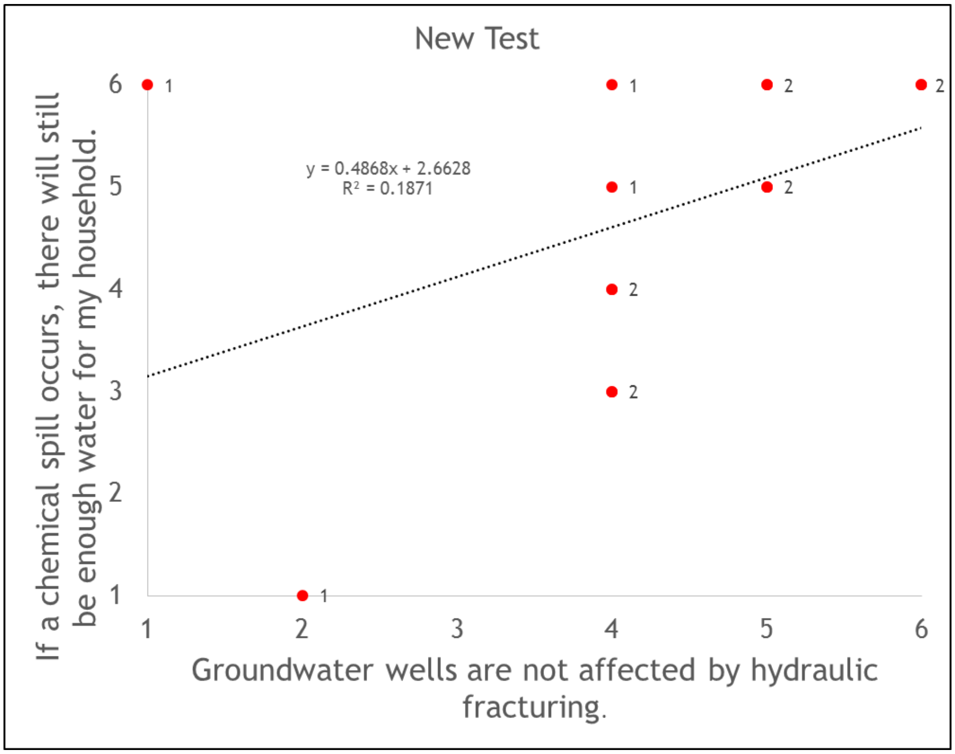


Figure 3b: Comparison Between Questions q23_3 and q23_5 for New Tests (The numbers next to the specific opinions represent the number of residents with that specific opinion.)

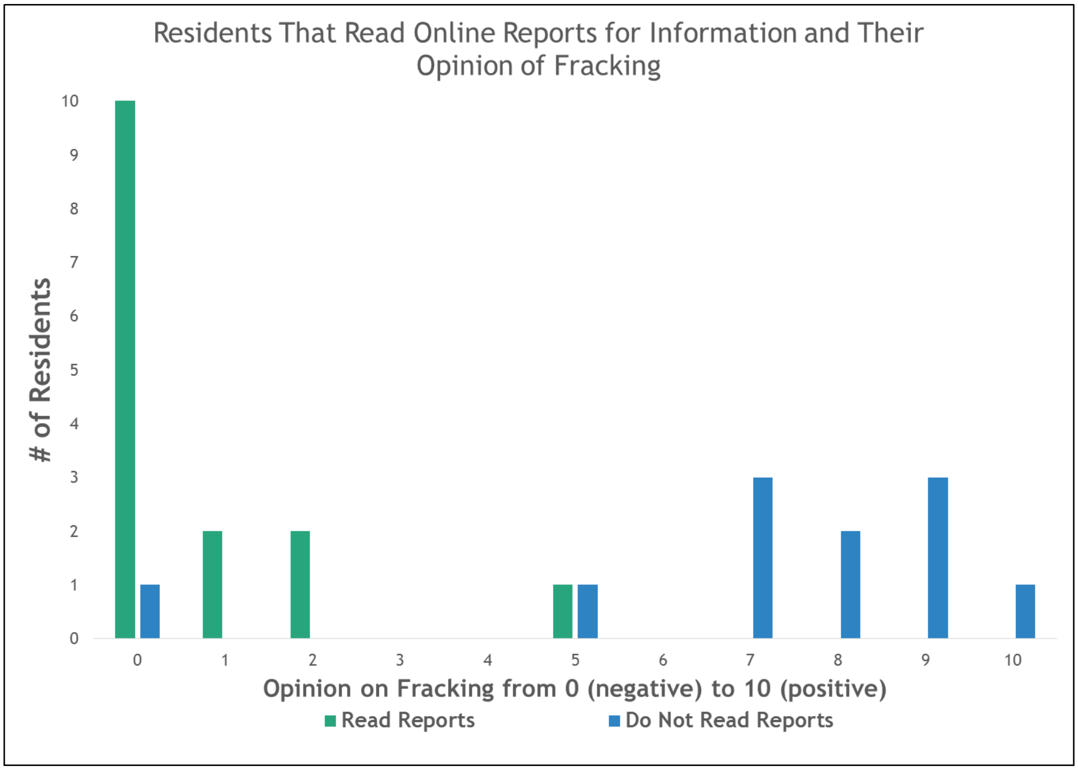


Figure 4: Comparison of Questions q13_4 and q43_1

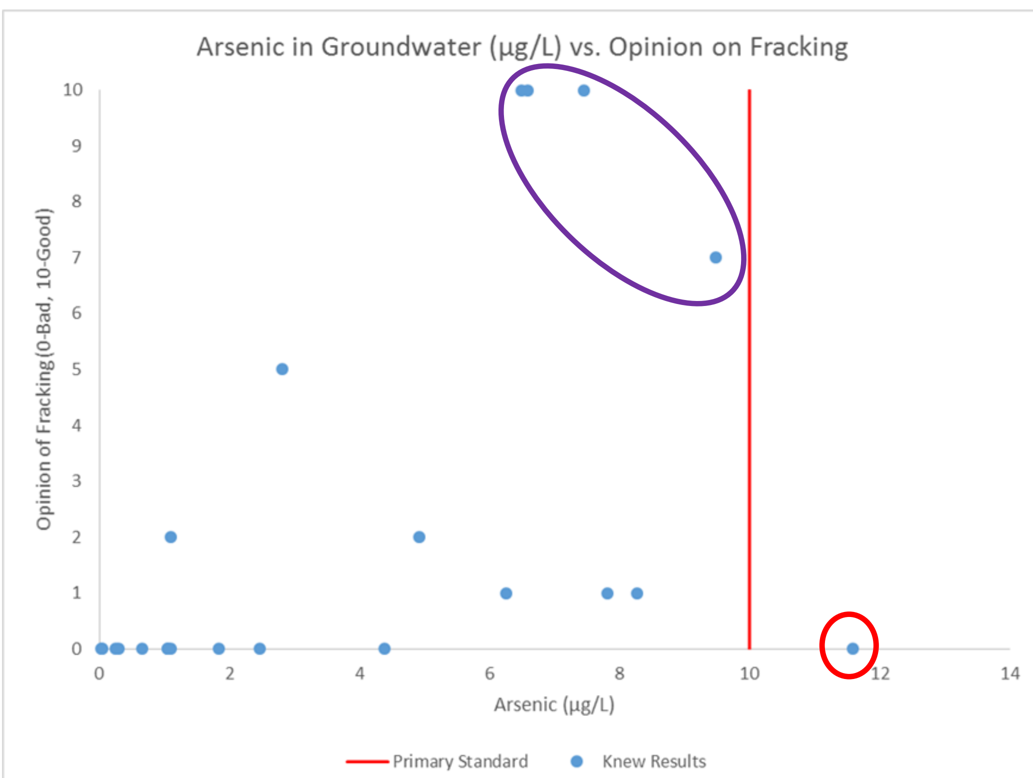


Figure 6: Arsenic Concentrations (µg/L) Compared to Water Quality Opinion

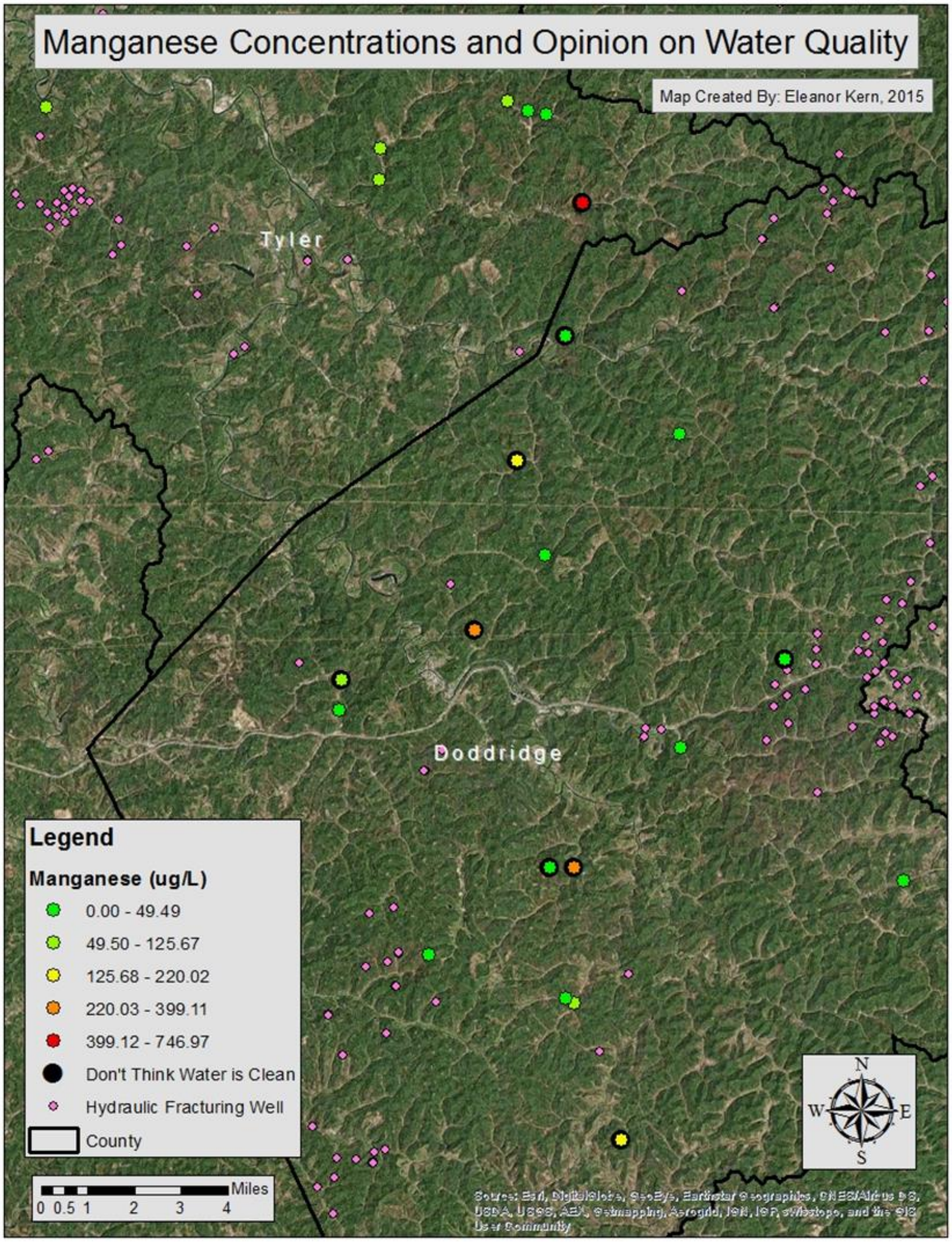


Figure 7: Manganese Concentrations (μg/L) and Survey Participants Who Don't Think Their Water is Clean

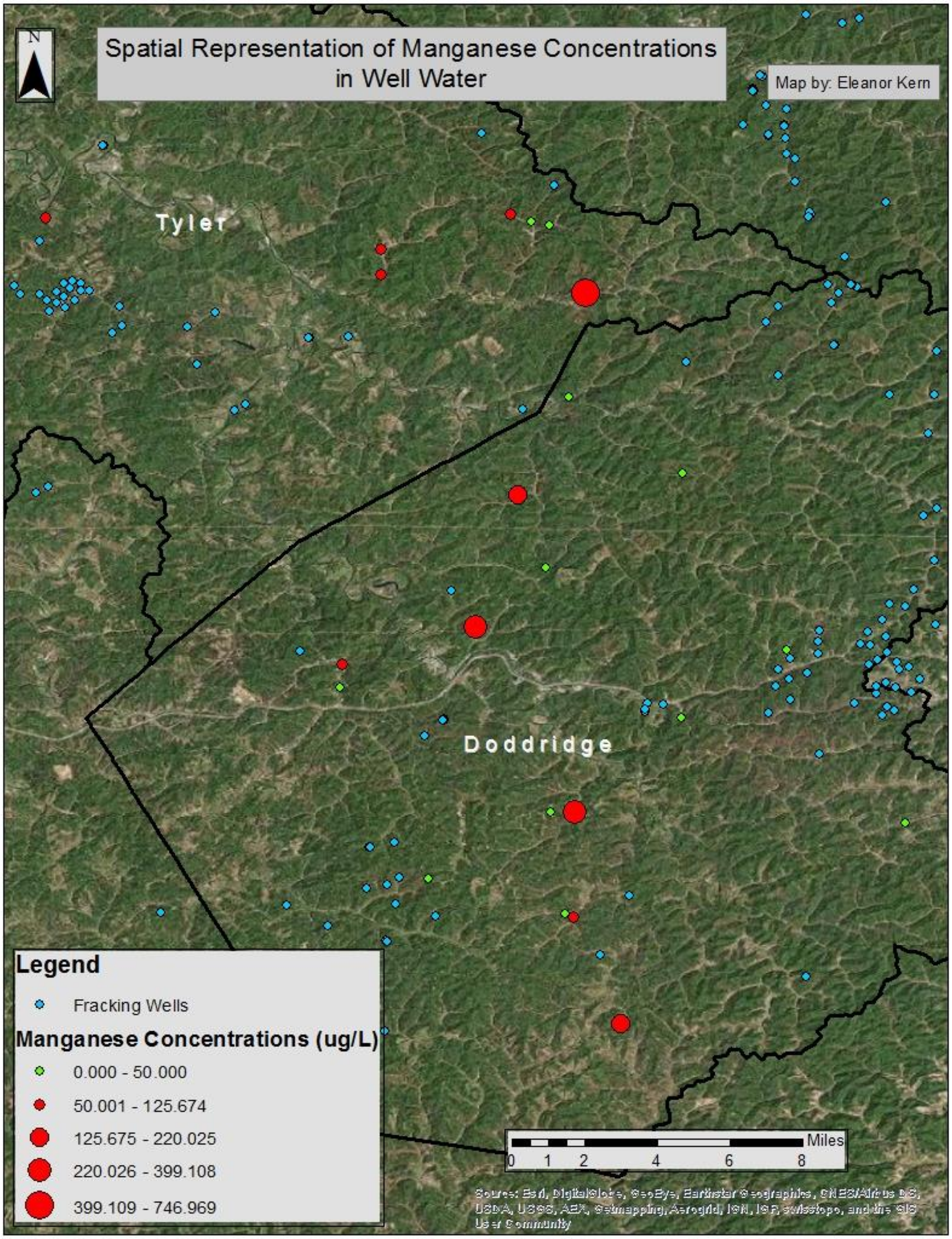


Figure 8: Manganese Concentrations in Resident Well Water Samples

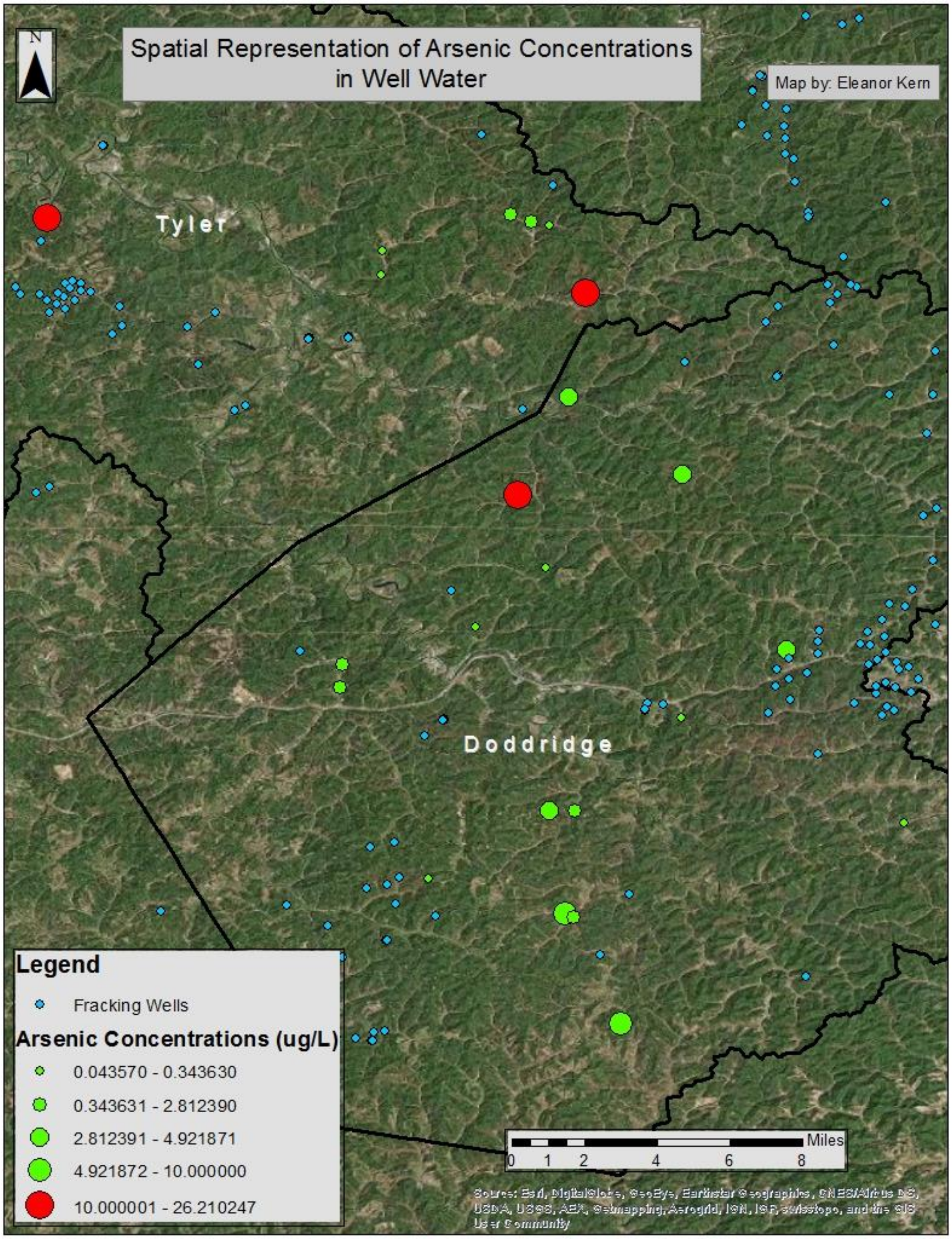


Figure 9: Arsenic Concentrations in Resident Well Water Samples

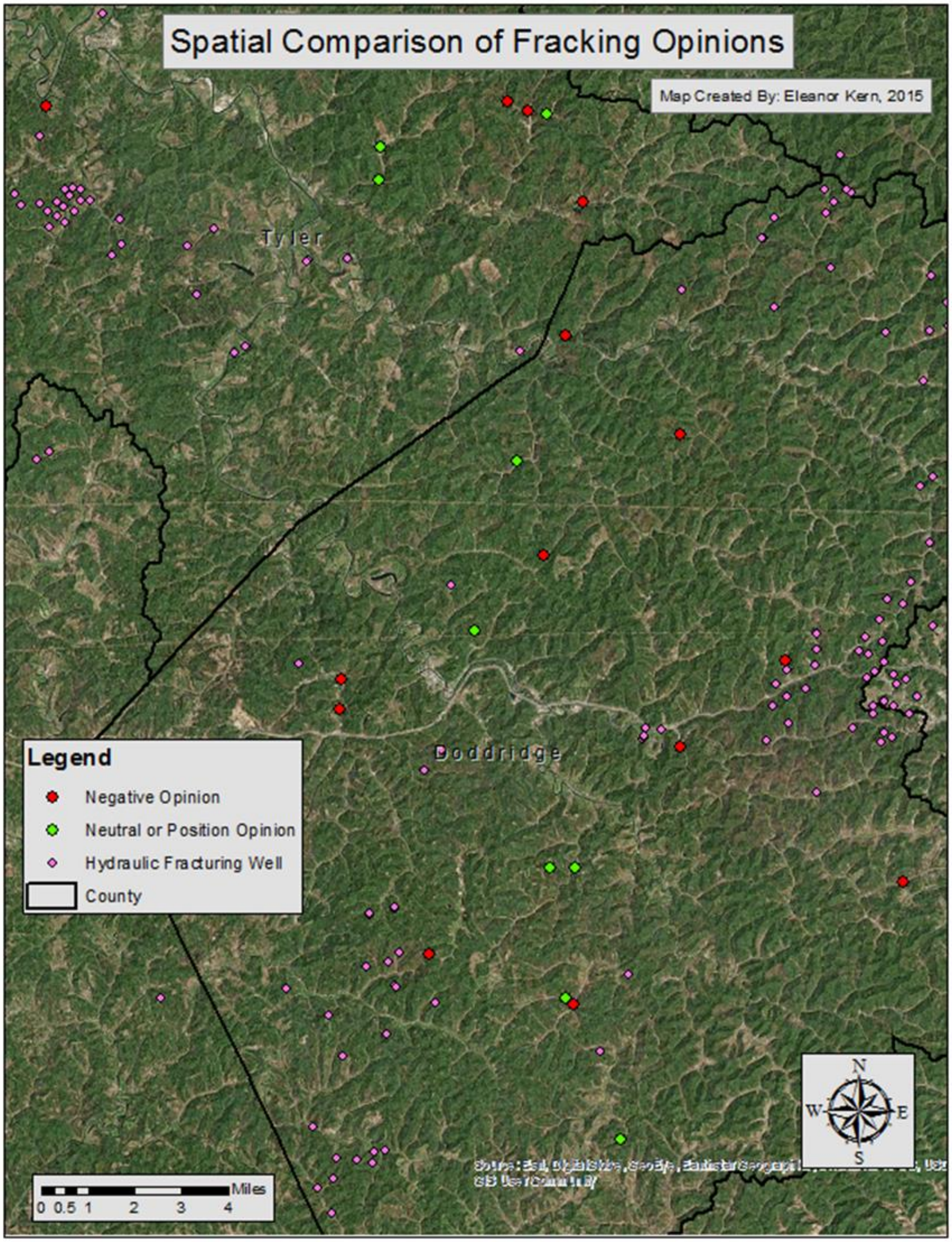


Figure 10: Spatial Representation of Those with Negative Opinions on Fracking

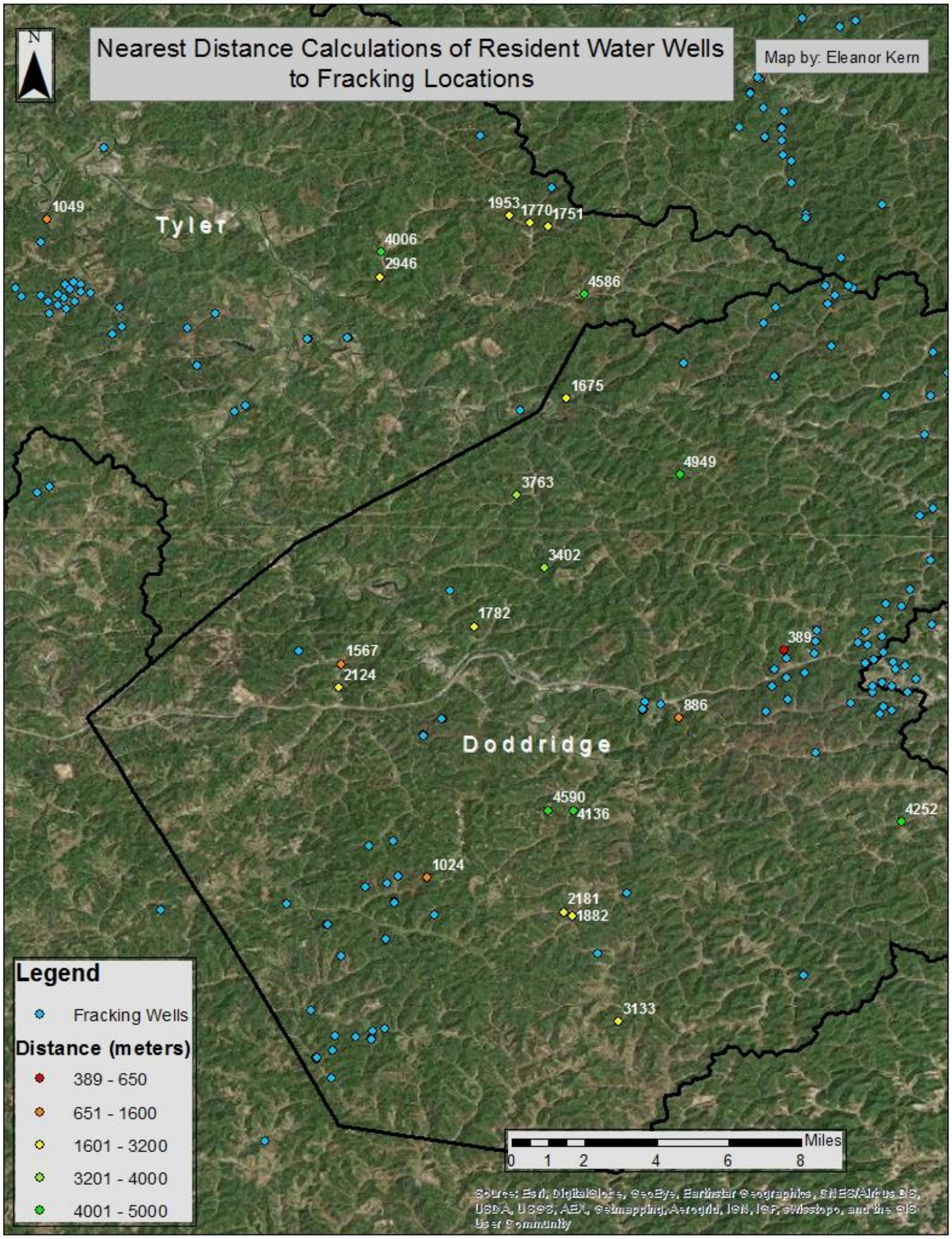


Figure 11: Nearest Distance Calculations of Resident Water Wells to Fracking Locations

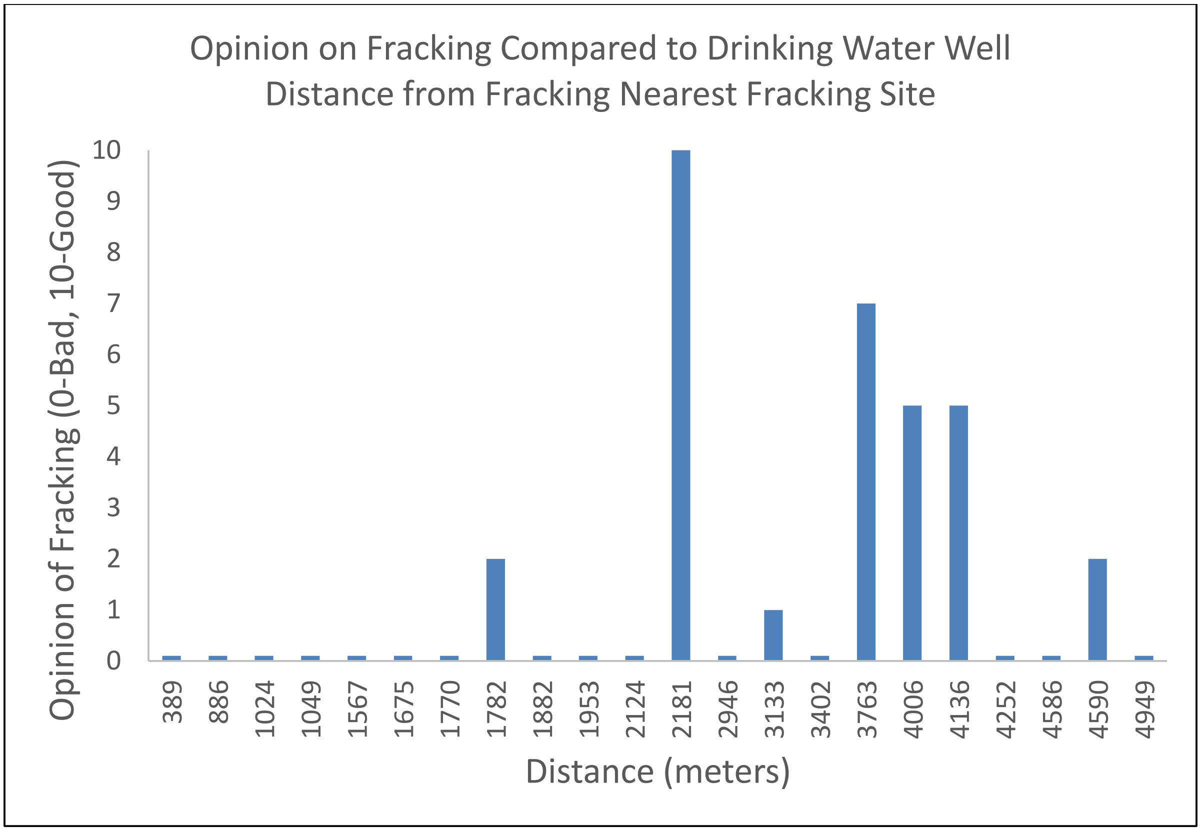


Figure 12: Graphical Representation of Opinion on Fracking Based on Distance of Resident Water Well to Nearest Fracking Site